STRANGE-QUARK VECTOR CURRENT PSEUDOSCALAR-MESON TRANSITION FORM FACTORS[1]

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Abstract

Similarly to the electromagnetic pseudoscalar-meson transition form factors one can define also strange-quark vector current pseudoscalar-meson transition form factors, contributing only to a behaviour of the isoscalar parts of the previous ones. Their explicit form is found by constructing unitary and analytic models of the strange pseudoscalar-meson transition form factors dependent only on ω and ϕ coupling constant ratios as a free parameters. Numerical values of these ratios are then determined from the corresponding pseudoscalar-meson transition form factors by employing the ω-ϕ mixing and a special assumption on the coupling of the quark components of vector-meson wave functions to flavour component of currents under consideration.

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1 Introduction

During the last years there was an experimental effort [1]-[3] to confirm non-zero contributions of sea strange quark-antiquark pairs to the structure of nucleons, which are built by nonstrange up and down quarks. The results of those experiments were

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values of the nucleon strange electric and magnetic form factors (FF's), or of their combinations at nonzero values of the four-momentum transfer squared $t = -Q^2$.

On the other hand there are various theoretical approaches [4]-[8]in the framework of which one can predict strange electric and magnetic or strange Dirac and Pauli FF's of nucleons. One of these approaches [8] utilizing the unitary and analytic models of electromagnetic (EM) structure of hadrons [9], appeared in a description of the scarce experimental information on nucleons to be successful and it can be directly extended also to the pseudoscalar-meson transition FF's $F_{\gamma P}(t)$.

The idea consists in the following. If the unitary and analytic models, with all known properties of the EM pseudoscalar-meson transition FF's are constructed $F^{EM}_{\gamma P}(t) = f[t; a_\rho, a_\omega, a_{phi}]$, where the free parameters $a_\rho = (f_{\rho\gamma P}/f^{EM}_\rho)$, $a_\omega = (f_{\omega\gamma P}/f^{EM}_\omega)$, $a_\phi = (f_{\phi\gamma P}/f^{EM}_\phi)$ are determined by a comparison of the model with all existing data on $|F^{EM}_{\gamma P}(t)|$ in space-like and time-like region simultaneously, and unitary and analytic models of the same inner structure (besides the asymptotic behaviour and normalization) with all known properties of the strange-quark vector current pseudoscalar-meson transition FF's are established $F^s_{\gamma P}(t){=}g[t; b_\omega, b_{phi}]$ with unknown parameters $b_\omega{=}(f_{\omega\gamma P}/f^s_\omega)$, $b_\phi{=}(f_{\phi\gamma P}/f^s_\phi)$, then the latter parameters are determined from the known a_ω, a_ϕ by the relations [4]

$$\begin{aligned} b_\omega &= -\sqrt{6}\frac{\sin\epsilon}{\sin(\epsilon+\theta_0)}a_\omega \\ b_\phi &= -\sqrt{6}\frac{\cos\epsilon}{\cos(\epsilon+\theta_0)}a_\phi, \end{aligned} \tag{1}$$

where $\epsilon = 3.7^\circ$ is deviation from the ideally ω-ϕ mixing angle $\theta_0 = 35.3^\circ$.

In the next section we review briefly the unitary and analytic model of EM pseudoscalar-meson transition FF's. The section 3 is devoted to a prediction of behaviours of strange-quark vector current pseudoscalar-meson transition FF's. In the last section we present conclusions and discussion.

2 EM Pseudoscalar-meson transition form factors

The EM pseudoscalar-meson transition FF's are understood to be functions $F^{EM}_{\gamma P}(t)$ describing any $\gamma^* \to \gamma P$ transition, where P can be π^0, η and η'. Only recently a progress in the EM pseudoscalar-meson transition FF's was achieved [10] thanks to the sophisticated unitary and anlytic model of EM structure of hadrons [9] and an appearance of a new experimental information, especially in the time-like region [11]. There is a single FF for each $\gamma^* \to \gamma P$ transition to be defined by a parametrization of the matrix element of the EM current $J^{EM}_\mu = 2/3\bar{u}\gamma_\mu u - 1/3\bar{d}\gamma_\mu d - 1/3\bar{s}\gamma s$

$$\langle P(p)\gamma(k)|J^{EM}_\mu|0\rangle = \epsilon_{\mu\nu\alpha\beta}p^\nu\epsilon^\alpha k^\beta F^{EM}_{\gamma P}(t), \qquad (2)$$

where ϵ^α is the polarization vector of the photon γ, $\epsilon_{\mu\nu\alpha\beta}$ appears as only the pseudoscalar-meson belongs to the abnormal spin-parity series. Every $F^{EM}_{\gamma P}(t)$ for $P = \pi^0$, η, η' in the framework of the unitary and analytic model of the EM structure of hadrons takes the form

$$F^{EM}_{\gamma P}(t) = F^{I=0}_{\gamma P}[V(t)] + F^{I=1}_{\gamma P}[W(t)] \qquad (3)$$

with

$$F^{I=0}_{\gamma P}[V(t)] = \left(\frac{1-V^2}{1-V_N^2}\right)^2 \{\frac{1}{2}F^{EM}_{\gamma P}(0)H(\omega') + [L(\omega) - H(\omega')]a_\omega + [L(\phi) - H(\omega')]a_\phi\}$$

$$F^{I=1}_{\gamma P}[W(t)] = \left(\frac{1-W^2}{1-W_N^2}\right)^2 \{\frac{1}{2}F^{EM}_{\gamma P}(0)H(\rho) + [L(\rho) - H(\rho')]a_\rho\}$$

where $V(W)$ is the conformal mapping

$$V(t) = i\frac{\sqrt{q^{I=0}_{in} + q} - \sqrt{q^{I=0}_{in} - q}}{\sqrt{q^{I=0}_{in} + q} + \sqrt{q^{I=0}_{in} - q}} \qquad (4)$$

$$q = [(t - t_0)/t_0]^{1/2}; \quad q^{I=0}_{in} = [(t^{I=0}_{in} - t_0)/t_0]^{1/2}$$

of the four-sheeted Riemann surface in t-variable into one V-plane (W-plane),

$$F^{EM}_{\gamma P}(0) = \frac{2}{\alpha m_P}\sqrt{\frac{\Gamma(P \to \gamma\gamma)}{\pi m_P}}, \qquad (5)$$

$t_0 = m^2_{\pi^0}$, $t_{in}^{I=0}$ and $t_{in}^{I=1}$ are the effective square-root branch points including in average contributions of all higher important thresholds in both, isoscalar and isovector case, respectively, and

$$L(s) = \frac{(V_N - V_s)(V_N - V_s^*)(V_N - 1/V_s)(V_N - 1/V_s^*)}{(V - V_s)(V - V_s^*)(V - 1/V_s)(V - 1/V_s^*)}$$

$$s = \omega, \phi, \quad V_N = V(t)_{|t=0}$$

$$H(\omega') = \frac{(V_N - V_{\omega'})(V_N - V_{\omega'}^*)(V_N + V_{\omega'})(V_N + V_{\omega'}^*)}{(V - V_{\omega'})(V - V_{\omega'}^*)(V + V_{\omega'})(V + V_{\omega'}^*)}$$

$$L\rho = \frac{(W_N - W_\rho)(W_N - W_\rho^*)(W_N - 1/W_\rho)(W_N - 1/W_\rho^*)}{(W - W_\rho)(W - W_\rho^*)(W - 1/W_\rho)(W - 1/W_\rho^*)}; \quad W_N = W(t)_{|t=0}$$

$$H\rho' = \frac{(W_N - W_{\rho'})(W_N - W_\rho^*)(W_N + W_{\rho'})(W_N + W_{\rho'}^*)}{(W - W_{\rho'})(W - W_{\rho'}^*)(W + W_{\rho'})(W + W_{\rho'}^*)}.$$

If in a comparison of (3) with existing data masses and width of all vector-mesons under consideration are fixed at the table values, then other free parameters of the model acquire the following values:

$$\pi^{\mathbf{0}}: \quad \chi^2/ndf = 0.79; \quad t_{in}^{I=0} = 0.9714 GeV^2; \quad t_{in}^{I=1} = 1.0198 GeV^2; \tag{6}$$

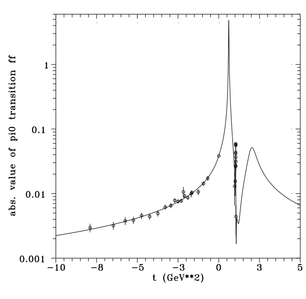

Figure 1: π^0 transition form factor

$$(f_{\omega\gamma\pi^0}/f_\omega^{EM}) = 0.0120 \pm 0.0002; (f_{\phi\gamma\pi^0}/f_\phi^{EM}) = -0.0002 \pm 0.0001;$$

$$(f_{\rho\gamma\pi^0}/f_\rho^{EM}) = 0.0208 \pm 0.0006;$$

$$\eta: \quad \chi^2/ndf = 1.08; \quad t_{in}^{I=0} = 0.6081 GeV^2; \quad t_{in}^{I=1} = 0.6299 GeV^2; \tag{7}$$

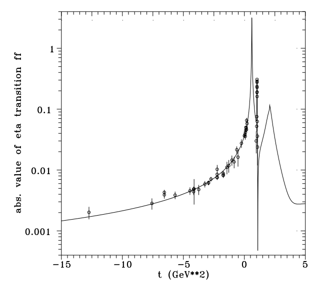

Figure 2: η transition form factor.

$$(f_{\omega\gamma\eta}/f_{\omega}^{EM}) = 0.0201 \pm 0.0020; (f_{\phi\gamma\eta}/f_{\phi}^{EM}) = -0.0013 \pm 0.0001;$$

$$(f_{\rho\gamma\eta}/f_{\rho}^{EM}) = 0.0119 \pm 0.0012$$

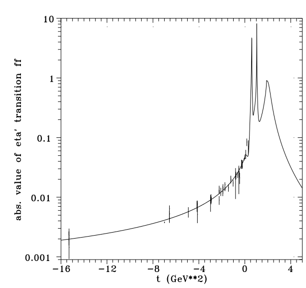

Figure 3: η' transition form factor

$$\eta' : \quad \chi^2/ndf = 1.29; \quad t_{in}^{I=0} = 1.0106 GeV^2; \quad t_{in}^{I=1} = 0.9578 GeV^2; \qquad (8)$$

$$(f_{\omega\gamma\eta'}/f_{\omega}^{EM}) = -0.1049 \pm 0.0011; (f_{\phi\gamma\eta'}/f_{\phi}^{EM}) = 0.0757 \pm 0.0017;$$

$$(f_{\rho\gamma\eta'}/f_{\rho}^{EM}) = 0.0859 \pm 0.0009$$

and a prediction of behaviours of the corresponding FF's and their comparison with exiting data are graphically presented in Figs. 1-3.

3 Strange pseudoscalar-meson transition form factors

The strange-quark vector current pseudoscalar-meson transition FF's $F^s_{\gamma P}(t)$ can be defined analogically to (2) by the parametrization

$$\langle P(p)\gamma(k)|J^s_\mu\rangle = \epsilon_{\mu\nu\alpha\beta}p^\nu\epsilon^\alpha k^\beta F^s_{\gamma P}(t) \tag{9}$$

where J^s_{mu}=$\bar{s}\gamma_\mu s$ is the strange-quark vector current.

Since the isospin of the strange quark s is zero, then the strange-quark vector current pseudoscalar-meson transition FF's $F^s_{\gamma P}(t)$ can contribute only to the isoscalar parts of $F^{EM}_{\gamma P}(t)$, from where it directly follows that $F^s_{\gamma P}(t)$ are saturated (unlike $F^{EM}_{\gamma P}(t)$) only by isoscalar vector-mesons. However, since the total strangeness of P and γ is zero, then their normalizations take the form

$$F^s_{\gamma P}(0) = 0. \tag{10}$$

The asymptotic behaviours of the strange pseudoscalar-meson transition FF's are

$$F^s_{\gamma P}(t)_{|_{|t|\to\infty}} \sim t^{-3} \tag{11}$$

as there are another two $\bar{s}s$ quarks contributing to the structure of P.

Analytic properties of $F^s_{\gamma P}(t)$ are identical with analytic properties of $F^{I=0}_{\gamma P}(t)$.

Taking into account all the abovementioned properties in a construction of the unitary and analytic models of $F^s_{\gamma P}(t)$ we start with the corresponding VMD parametrization

$$\widetilde{F}^s_{\gamma P}(t) = \sum_{i=\omega,\phi,\omega'} \frac{m_i^2}{m_i^2 - t}(f_{i\gamma P}/f^s_i) \tag{12}$$

where f^s_i is a coupling of the strangeness current to vector meson i=ω, ϕ, ω' and we use the FF denotation $\widetilde{F}^s_{\gamma P}(t)$ as it has still the VMD asymptotic behaviour.

Requirement of the normalization (10) leads to the expression

$$\begin{aligned}\widetilde{F}^s_{\gamma P}(t) &= \left[\frac{m_\omega^2}{m_\omega^2 - t} - \frac{m_{\omega'}^2}{m_{\omega'}^2 - t}\right] b_\omega + \\ &+ \left[\frac{m_\phi^2}{m_\phi^2 - t} - \frac{m_{\omega'}^2}{m_{\omega'}^2 - t}\right] b_\phi.\end{aligned} \tag{13}$$

Then analogically to (3) the unitary and analytic model of $\widetilde{F}^s_{\gamma P}(t)$ takes the form

$$\widetilde{F}_{\gamma P}(t) = \left(\frac{1-V^2}{1-V_N^2}\right)^2 \cdot \tag{14}$$
$$\cdot \left\{\left[\frac{(V_N-V_\omega)(V_N-V_\omega^*)(V_N-1/V_\omega)(V_N-1/V_\omega^*)}{(V-V_\omega)(V-V_\omega^*)(V-1/V_\omega)(V-1/V_\omega^*)} - \right.\right.$$
$$- \left.\frac{(V_N-V_{\omega'})(V_N-V_{\omega'}^*)(V_N+V_{\omega'})(V_N+V_{\omega'}^*)}{(V-V_{\omega'})(V-V_{\omega'}^*)(V+V_{\omega'})(V+V_{\omega'}^*)}\right] b_\omega +$$
$$+ \left[\frac{(V_N-V_\phi)(V_N-V_\phi^*)(V_N+V_\phi)(V_N+V_\phi^*)}{(V-V_\phi)(V-V_\phi^*)(V+V_\phi)(V+V_\phi^*)} - \right.$$
$$- \left.\left.\frac{(V_N-V_{\omega'})(V_N-V_{\omega'}^*)(V_N+V_{\omega'})(V_N+V_{\omega'}^*)}{(V-V_{\omega'})(V-V_{\omega'}^*)(V^*+V_{\omega'})(V+V_{\omega'}^*)}\right] b_\phi\right\}.$$

but still with the VMD asymptotics. However, taking into account a change of the exponent in the asymptotic term

$$\left(\frac{1-V^2}{1-V_N^2}\right)^2 \to \left(\frac{1-V^2}{1-V_N^2}\right)^{2n}, \quad n = 1, 2, 3, .. \tag{15}$$

leading to the change of the asymptotic behavior

$$|_{|t|\to\infty} \sim t^{-1} \to |_{|t|\to\infty} \sim t^{-n} \tag{16}$$

of any unitary and analytic FF, one can multiply both sides of (14) by the factor

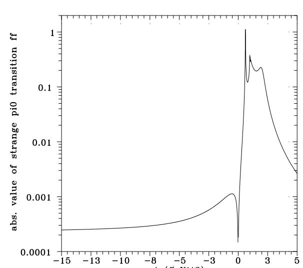

Figure 4: Strange π^0 transition form factor

$\left(\frac{1-V^2}{1-V_N^2}\right)^n$ and redefine the FF

$$F^s_{\gamma P}(t) = \widetilde{F}^s_{\gamma P}(t)\left(\frac{1-V^2}{1-V_N^2}\right)^4, \tag{17}$$

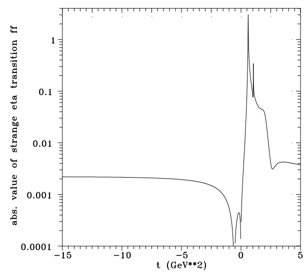

Figure 5: Strange η transition form factor.

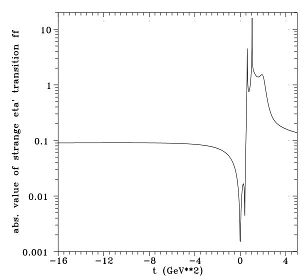

Figure 6: Strange η' transition form factor.

in order to achieve the unitary and analytic model of $F^s_{\gamma P}(t)$ with the required asymptotic behaviour (11) and dependent only on unknown b_ω and b_ϕ to be determined by the relations (1) from the values of a_ω , a_ϕ given by (6)-(8).

Now taking into account the numerical values (6)-(8) and utilizing relations (1) one gets for

$$\begin{aligned}
\pi_{\mathbf{0}}: \quad & (f_{\omega\gamma\pi_0}/f^s_\omega) = +0.0062; \qquad & (f_{\phi\gamma\pi_0}/f^s_\phi) = +0.0006; \\
\eta: \quad & (f_{\omega\gamma\eta}/f^s_\omega) = -0.0050; \qquad & (f_{\phi\gamma\eta}/f^s_\phi) = +0.0041; \\
\eta': \quad & (f_{\omega\gamma\eta'}/f^s_\omega) = +0.0263; \qquad & (f_{\phi\gamma\eta'}/f^s_\phi) = -0.2386
\end{aligned} \tag{18}$$

and a prediction of behaviours of the corresponding strange pseudoscalar-meson transition FF's are graphically presented in Figs. 4-6.

4 Conclusions and discussion

The method of a behaviour of strange-quark vector current nucleon FF behaviours, which is interesting in relation to an experimental effort to confirm non-zero contributions of sea strange quark-antiquark pairs to the nucleon structure, is extended to pseudoscalar-meson transition FF's. An explicit form of strange-quark vector current of pseudoscalar-meson transition FF's is found by constructing unitary and analytic models dependent only on the ω and ϕ coupling constant ratios as only unknown parameters. Their numerical values are determined from the corresponding coupling constant ratios of the EM pseudoscalar-meson transition FF's by employing the ω-ϕ mixing and a special assumption on the coupling of the quark components of vector-meson wave functions to flavour components of quark-current under consideration.

However, we don't know how to measure the strange pseudoscalar-meson transition FF's.

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